

What can we learn if we measure the indoor and outdoor number concentration of PM2.5 at the same time?



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Abstract

Purpose / Context - Indoor airborne bioaerosol, which has an outdoor origin, plays an important role in determining the exposure of humans to bioaerosol, since people spend most of their time indoors. However, there are few studies focusing on the indoor bioaerosols that are generated outdoors.

Methodology / Approach - In this study, indoor-outdoor size resolved concentrations of airborne fluorescent bioaerosol in an office room were measured continuously for six days (144 h) by using a fluorescent bioaerosol detector. We focused on the particulate matter with an aerodynamic diameter $<2.5\mu\text{m}$.

Results – The ratios of indoor to outdoor particle concentration and those of bioaerosol to aerosol concentrations in various size ranges vary significantly. The measured and predicted concentrations have a linear relationship for the studied size fractions, with R^2 of all size fractions larger than 0.83.

Key Findings / Implications – Correlations between indoor and outdoor bioaerosol concentrations show significant concentration-attenuation and time-lag over time.

Originality - A two-parameter, semi-empirical model was proposed to predict the concentration of indoor bioaerosol with outdoor origin.

Keywords - *Bioaerosol; Indoor air; Outdoor origin; WIBS; Size distribution*



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1. Introduction

Epidemiological and toxicological researches have shown that exposure to PM (Particle Matter) in air can increase the rates of cardiac and respiratory morbidity, premature death, hospital admission and mortality (Pope et al., 2004, Davidson et al., 2005, Pope and Dockery, 2006, USEPA, 2009, Lim et al., 2012, Chen et al., 2013). Exposure to bioaerosol can cause atopic diseases and other adverse health effects, such as asthma, allergic, toxic, rheumatic, and infectious diseases (Burger, 1990, Menetrez et al., 2001, Hanski et al., 2012). Ambient air pollution exposure is closely linked to indoor environment. On the one hand, people spend 85–90% of the time indoors (Brauer et al., 2000, Klepeis et al., 2001, Adgate et al., 2002, Wang et al., 2010). On the other hand, indoor PM_{2.5} is principally contributed by outdoor infiltration, if do not consider the origin of indoor human activities, the gas to solid phase transformation and indoor PM re-suspension.

In general, the relationship of PM between indoor and outdoor environment can be described by the mass balance equation. When indoor particles generation can ignore, the relationship between indoor and outdoor PM depends on three key parameters: air change rate, penetration efficiency and deposition rate, based on the mass balance equations. In these parameters except a are a function of both time and particle size (Chen and Zhao, 2011). Infiltration becomes the main ventilation mode without the mechanical ventilation, the penetration determines how much ambient particle can be brought from outside into the indoor environment and deposition on indoor-surface is one of the major particle losses (Chao et al., 2003, Hoek et al., 2008). The fine particulates are dominated indoors because most large size particles in suspended particulates are removed by the penetration process during airflow across building enclosure (Liu and Nazaroff, 2001, Chao et al., 2003, Chen et al., 2012). The penetration efficiency depends on the geometry of building gaps, the differential pressure between indoor and outdoor and the size spectrum of particles (Liu and Nazaroff, 2001, Chao et al., 2003, Chen et al., 2012). Nevertheless, the fine particulates are mainly removed by the mechanisms of diffusion and thermophoresis effect (Mak et al., 2011). Particularly, the effect of filter efficiency will replace penetration efficiency when using mechanical ventilation. Overall, estimates of the infiltration factor generated using dynamic models and infiltration surrogates show good agreement (Diapouli et al., 2013).

However, there are very few studies focusing on indoor bioaerosols that are generated outdoors. In the present study, indoor emissions were controlled strictly to ensure that indoor bioaerosols originate entirely from an outdoor environment, thus the infiltration factor, which is the parameter quantifying the contribution of outdoor bioaerosols could be obtained. A model that can predict the indoor bioaerosol concentration with an outdoor origin was developed. Particle size distributions and concentrations of indoor and outdoor fluorescent primary biological aerosol particles (FBAP) were recorded.

2. Methods

2.1 Study design

Aerosol measurements were performed continuously for a total of 144 h, from 10/03/2015 to 16/03/2015. Indoor and outdoor measurements were made using a single WIBS-4A, which records the optical size and levels of the sphericity, in addition to the fluorescence emission matrix from individual particles at a constant sample flow rate of 0.3 L/min (total flow: 2.5 L/min, sample flow: 0.3 L/min, and sheath flow: 2.2 L/min). Continuous measurements of indoor and outdoor bioaerosol concentration relied on a single WIBS instrument using an automated control box, consisting of two globe valves (KLD20S 2-way motorized ball valve) and a timer device controlling the switch of the measured aerosol between the indoor and outdoor environment passing through the spectrometer every 5 minutes. The waveband WIBS 4A is a single particle UV-induced fluorescence spectrometer. It excites and detects fluorescence in particles sized from 0.5 to 15 µm, by using two UV xenon lamps that provide two sequential ultraviolet pulses centered at 280 and 370 nm. Uncertainties related to WIBS measurement.

2.2 Analytical model

The concentration of indoor PM_{2.5} can be evaluated as a function of the infiltration rate ($F(t)$) and outdoor PM2.5 concentration ($C_{out}(t)$), when indoor particles generation can ignore

$$C_{in}(t) = F(t)C_{out}(t) \quad (1)$$

When use the steady-state assumption from the mass balance equation, the equation can be described as:

$$C_{in} = \frac{aP}{a+K} C_{out} \quad (2)$$

When use the dynamic assumption, the relationship of PM_{2.5} between indoor and outdoor environment can be described by the mass balance equation:

$$V \frac{dC_{in}(t)}{dt} = aPVC_{out}(t) - (a+K)VC_{in}(t) + \dot{C} \quad (3)$$

Where $C_{in}(t)$ is the indoor PM concentration and $C_{out}(t)$ is the outdoor concentration ($\mu\text{g}/\text{m}^3$); a is the air change rate (h^{-1}); P is the penetration efficiency of particles; K is the deposition rate of particles (h^{-1}); V is the volume of the indoor space (m^3); \dot{C} is the indoor particles generation rate ($\mu\text{g}/\text{h}$).

Particularly, P can be describe as $1-\eta$ when using mechanical ventilation.

$$P = 1 - \eta \quad (4)$$

Where η is the filter efficiency.

Air change rates of the office were measured using the tracer gas decay method. Carbon dioxide gas was released and the concentration increased up to 2000 ppm. In our experiment room, only one process may add bioaerosol to the indoor air: infiltration through leaks in the building envelopes. Two processes may remove bioaerosol material: (1) ventilation airflow out of the building, and (2) deposition onto room surfaces. Thus the equation can be written as:

$$V \frac{dC_{in}(t)}{dt} = aPVC_{out}(t) - (a+K)VC_{in}(t) \quad (5)$$

Where V is the volume of the room (L), C_{in} the number concentration of indoor aerosol (#/L), a the air exchange rate in the room (h^{-1}), P the penetration ratio C_{out} the number concentration of outdoor aerosol (#/L), K the deposition rate (h^{-1}).

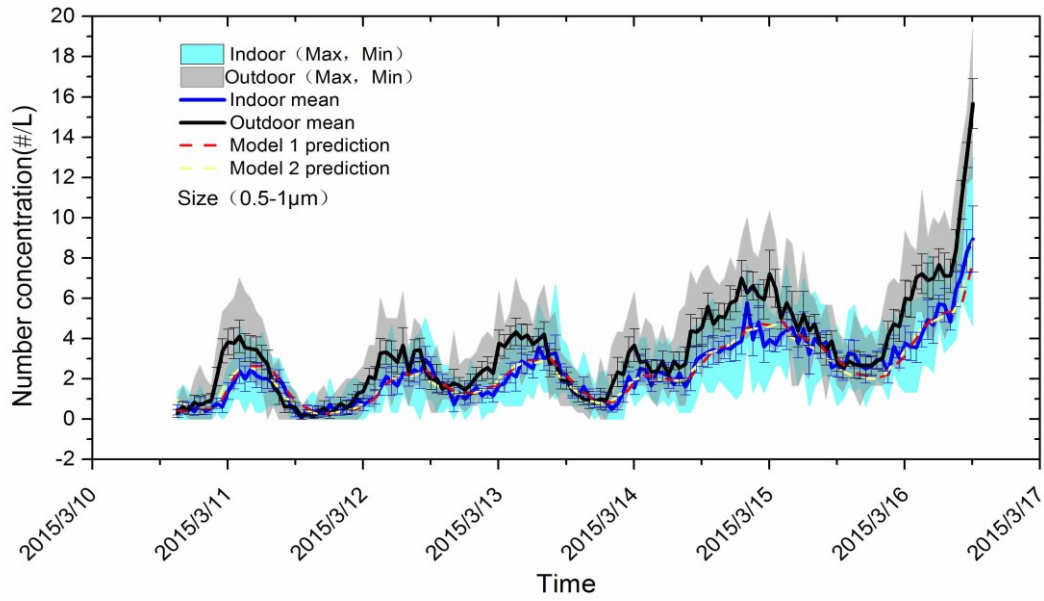
To show the result in a simpler way, we define $\phi = aP$, $\varphi = a+K$; then the equation can be written as:

$$\frac{dC_{in}(t)}{dt} = \phi C_{out}(t) - \varphi C_{in}(t) \quad (6)$$

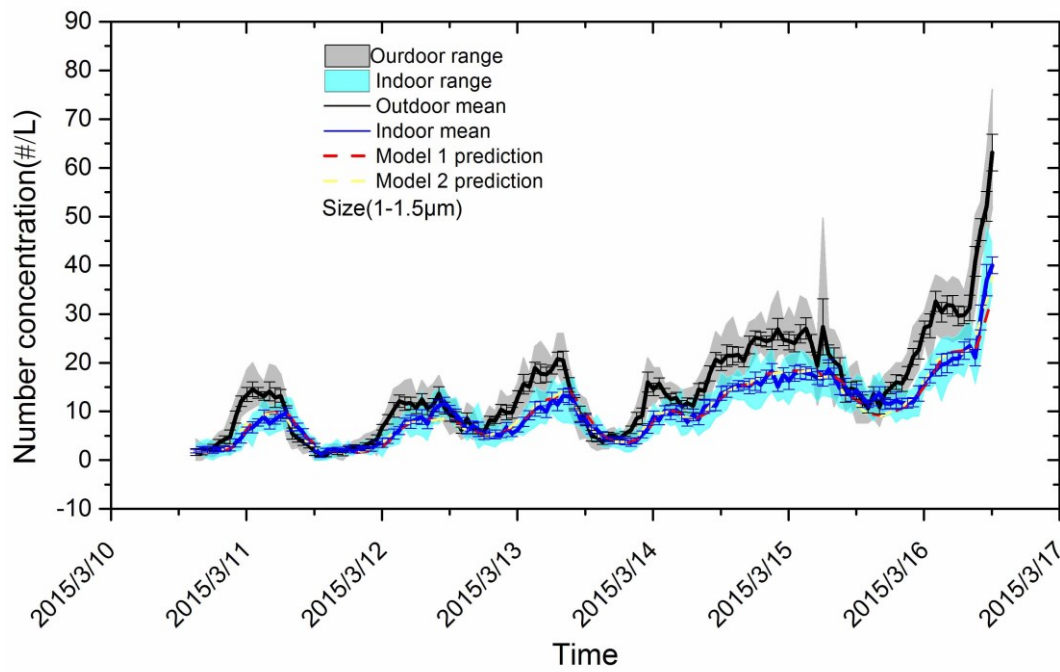
We assume that ϕ and φ are constant within certain time range.

3. Results

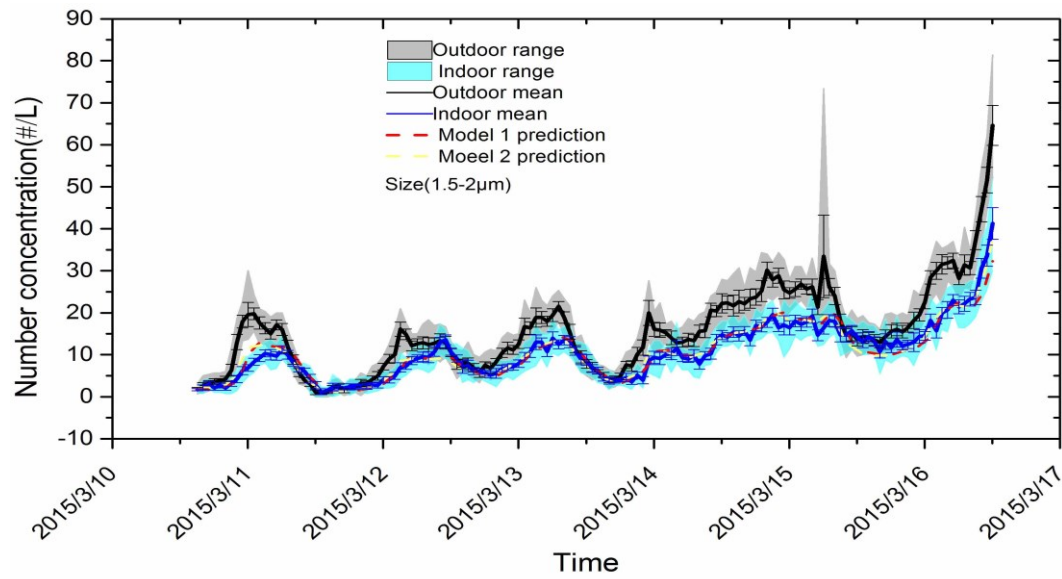
We analyze the size-resolved indoor-outdoor airborne bioaerosol in time series and use a mass balance equation to model the outdoor-indoor relationship. The number concentration of outdoor non- fluorescent aerosols and Bioaerosols, show a periodic fluctuation in all size ranges. The indoor concentration changes according to the outdoor conditions, but it shows significant concentration-attenuation and time-lag. The concentration of bioaerosols made up no more than 10% of non- fluorescent aerosols and the test result showed that the uncertainty there is in an hour, the lower is the concentration. The variation trend of bioaerosols and non- fluorescence aerosols is similar except for the changing amplitude. More detailed information can be found in Figure 1 (a, b, c and d).



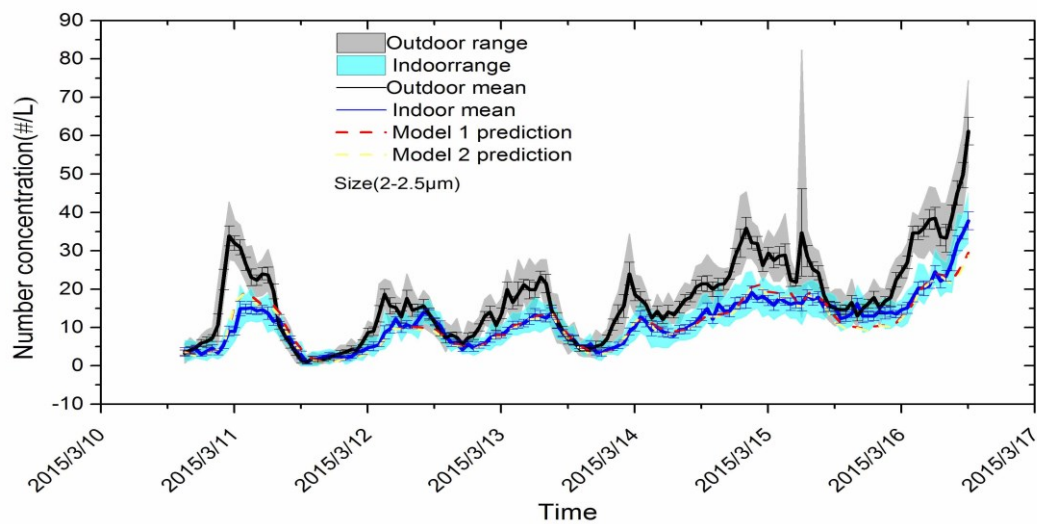
(a)



(b)



(c)



(d)

Figure 1. The indoor-outdoor concentration (\pm standard deviation) of bioaerosols with the model prediction in time series (We included all 144 h to calculate ϕ and φ , Model 2 used the first 70 h to calculate ϕ and φ , and it used the rest of the hours to verify the model. a: size 0.5-1.0 μm ; b: size 1.0-1.5 μm ; c: size 1.5-2.0 μm ; d: 2.0-2.5 μm .)

4. Discussion

The indoor bioaerosols of an outdoor origin are mostly fine particles. Therefore, we choose the airborne bioaerosol in the size range of 0.5 to 2.5 μm to build the two-parameter iteration model. The two-parameter iteration model does not completely conform to previous theoretical studies (Kulmala et al., 1999, Allen et al., 2012, Diapouli et al., 2013, Nazaroff, 2004). In the absence of indoor emission such as smoking, cooking, burning, and housekeeping in this study, the indoor particle sources can be ignored; resuspension is also ignored because of the low wind speed indoors in this study. Therefore, the indoor emission and resuspension are not incorporated in equation (5). The mass balance model assumes that the indoor space is well mixed and can be described using lumped parameters. In fact, the distribution of bioaerosols is not well-distributed in indoor space. The physical meaning of parameter ϕ

can be considered as the characteristic parameters of outdoor addition, so the parameter ϕ can be larger near the windows. In fact, it is very difficult to ensure species in the air uniformly distributed for a typical room. The age of air near windows is younger than room air age and the air change rate near windows can be larger than the mean air change rate according to the equation a . Moreover, the air change rate, penetration, and deposition are time-varying parameters in the strict sense. However, the two-parameter iteration model can predict indoor concentration successfully when the indoor flow field is under steady-state approximation.

The results from our week long experiment suggest that indoor concentrations of bioaerosols from outdoor environment are consistently lower than the concentrations outdoors, and ϕ/ϕ is approximately equal to the mean I/O ratio. This study offers a near real-time evaluation in the variation of indoor FBAP from the outdoor environment for a typical office without HVAC systems, which are yet abundant in many locations, and provide a universal model to assess the contribution of the outdoor bioaerosols.

5. Conclusion

The main conclusions could be drawn based on this study, in which the indoor and outdoor particle size distributions and concentrations of fluorescent primary biological aerosol particles (FBAPs) were measured using a Waveband Integrated Bioaerosol Sensor (WIBS) over six days:

1. Both indoor and outdoor bioaerosol size distributions can be fit with a two-mode, log-normal distribution (indoor $R^2=0.935$, outdoor $R^2=0.938$). AF distributions can also be fit with a log-normal distribution (indoor $R^2=0.992$, outdoor $R^2=0.992$).
2. Correlations between indoor and outdoor bioaerosol concentrations show significant concentration-attenuation and time-lag over time.
3. The concentrations measured by WIBS and predicted by the two-parameter, semi-empirical model have a linear relationship for the studied size fractions, with R^2 of all size fractions larger than 0.83.

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